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DEVELOPMENT OF THE RICE CONVECTION MODEL AS A SPACE WEATHER TOOL

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Final Report

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14. ABSTRACT
We have successfully demonstrated that the Rice Convection Model (RCM) can provide a superior space-weather product. The work under this preliminary project consisted of a modest amount of code development and more extensive validation and testing. By varying relevant RCM input parameters for different model runs of the same event, and assessing their effects on the computed output comparisons, we established cause and effect relationships and guidance on how best to represent new physics in the RCM for predictive capabilities purposes. At the conclusion of this project, we have at our disposal a modern and flexible inner magnetospheric model coupled to the ionosphere that is suitable for both scientific studies as well as a prediction tool. We are able to run the model faster than "real time" on sufficiently modern computational platforms for many days of magnetospheric time. In collaboration with the multi-agency Community Coordinated Modeling Center (CCMC), we made available a version of the RCM that runs in "real time". We plan on exploring additional ways to expand this line of work by finding ways to fund a more systematic effort in making the RCM a space weather prediction tool for magnetospheric and ionospheric studies relevant to space weather requirements.

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magnetospheric model, geomagnetic storms, sub-auroral polarization streams, SAPS, convection electric field, total electron content, TEC, ionospheric convection, plasmasphere

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1. INTRODUCTION

The MSFM (Magnetospheric Specification and Forecast Model), which was completed in the 1990's, was designed to calculate kilovolt electron fluxes at geosynchronous orbit and was coupled to a real-time version of the NASCAP code to provide estimates of spacecraft charging. The MSFM was essentially a simplified version of the 1990-vintage Rice Convection Model (RCM). With support from NASA and NSF, our group has concentrated since then on improving the RCM's scientific capabilities. We have been successful to the point where we think we have a first-principles code that can calculate geosynchronous charged particle fluxes more accurately than the MSFM could, while self-consistently calculating a wide range of other physical parameters of interest. The objective of this AFRL-funded work was to optimize and test the current version of the RCM, so that it will provide a realistic and comprehensive representation of the closed-field-line region of the magnetosphere.

This report summarizes technical accomplishments and science results that were obtained during the period of performance. Because the RCM self-consistently computes such a large set of relevant physical parameters in the inner magnetosphere and ionosphere, we focus only on the most relevant aspects of the code development and scientific studies.

2. BACKGROUND

During the period of performance, we made significant improvement to the RCM code to turn it into a robust tool that can be used for routine event simulations and prediction of a variety of physical parameters that are of practical importance for applications. In Section 3, we provide a brief description of the code improvements under the grant. Section 4 contains test results and discussion of the capabilities of the modern RCM code. Concluding remarks are presented in Section 5.

3. METHODS, ASSUMPTIONS, AND PROCEDURES

The Rice Convection Model (RCM) [1] is a modern numerical code that simulates the physics of the inner magnetospheric environment by evolving in time the Vlasov equation for the multi-species plasma distribution function that is isotropic in pitch angle, and concurrently integrating the coupled Poisson-type two-dimensional equation for the global ionospheric electrostatic potential. The code has been developed principally for scientific studies. It includes a large number of physics modules but required manual configuration and setup of input and other parameters.

3.1 Code Improvements

The following technical improvements were made to the RCM code to advance it to the level of a prediction-like tool:

Conversion to double precision. Through testing and validation of model results, we identified the need to convert the RCM code to double precision from the existing single precision. The

primary reason was lack of sufficient reproducibility of results on different platforms, caused by increased spatial grid resolution used in the RCM. The conversion was completed.

Implementation of the substorm current wedge in the inputted magnetic field model. In order to simulate substorm events, the code requires that the inputted time-varying magnetic field model undergoes a magnetic-local-time dependent "collapse" that represents the substorm current wedge. After various attempts, we found that the most robust scheme is the use of the "collapse parameter" in the Hilmer-Voigt [2] magnetic field model. Such a mechanism was originally implemented in MSFM in the late 1990s. We implemented this feature in the modern RCM.

Auroral particle precipitation signatures with TANGLE The module that computes precipitation of auroral energetic particles (electrons) has been generalized to compute auroral ionospheric electron density altitude profiles. Our previous version of this module, we evaluated field-line integrated Pedersen and Hall conductances using the moments (energy flux and average energy) of precipitating electrons using a semi-empirical relationship of Robinson et al. [3]. In the new version, we compute altitude profiles of the electron density in the auroral oval using parameterized results of the energy deposition calculation. This gives us the capability to estimate ionospheric global maps of the Total Electron Content (TEC) for routine comparison with GPS-derived maps regularly available from several data providers.

Implementation of magnetic field inputs. We implemented a series of options to use multiple magnetic field models in the RCM. Our additions funded by the grant are the magnetic field model TS04 (aka TS05) [4], which is a data-based high-resolution empirical model, and the TS07D model [5]. The later model is event-specific and requires a set of coefficients that are provided by APL on request.

Development of test particle module. We revised and improved a module that evolves test particles in the RCM-computed electromagnetic fields. The purpose of the module is to test the numerical schemes of the RCM as well as address the physics of particle injection and dynamics.

3.2 Validation and Testing

We performed several event simulations with the modern RCM that includes modifications as described above. In addition to idealized simulations, real event simulations were done for events listed in Table 1. Due to the large volume of the results, we are still working on validating RCM results and comparing them to multiple data sets. Our initial results indicate that RCM-predicted structure and magnitudes of the convection electric fields, particle precipitation, and TEC structuring are in good agreement with observations.

Table 1. Event simulations with RCM

Event	SuperDARN	GPS TEC	RCM	Min Dst
2001-03-31	-	✓	✓	-457 nT
2011-04-09	✓	✓	✓	-40 nT
2011-09-28	✓	✓	✓	-100 nT
2011-10-25	✓	✓	✓	-160 nT
2011-11-01	✓	✓	✓	-40 nT
2010-05-02		✓	✓	
2010-05-29		✓	✓	

4. RESULTS AND DISCUSSION

The following are some of the significant scientific findings.

4.1 Role of boundary conditions on Dst

To establish the role of the boundary conditions on the nightside plasma fluxes in modeling the Dst index during geomagnetic storms, we participated in the GEM metrics challenge that was run by the Community Coordinated Modeling Center (CCMC). We determined the optimal specification of the plasma fluxes boundary condition in the RCM that reproduces the predicted Dst index during geomagnetic storms with different drivers. Figure 1 present preliminary results of the Dst index predicted by the RCM (as well as a number of other inner magnetospheric models) for four different geomagnetic storms that differed in both intensity and their solar-wind drivers (these events are addition to those in Table 1). The full results were published in [6].

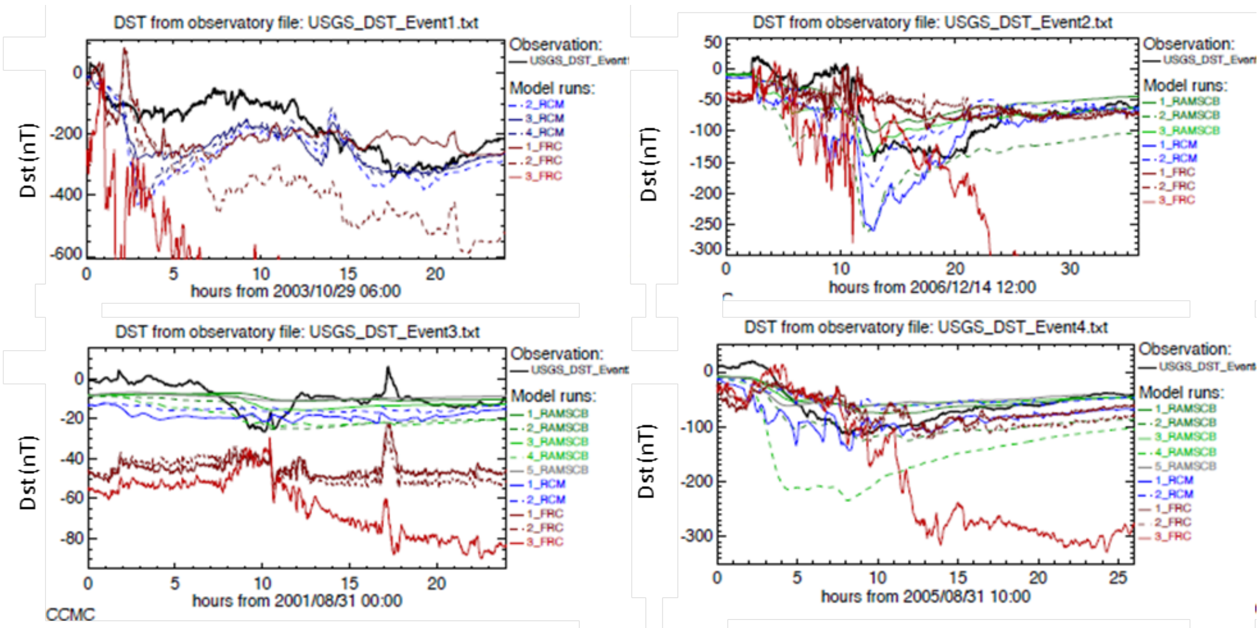

Figure 1. Comparison of Results for Predicting Dst [6].

4.2 Signatures of magnetospheric electric fields in the ionosphere

We simulated several geomagnetic storms that occurred in 2011-2012 for which new high-resolution measurements of two-dimensional convection flow maps are available from the newly constructed mid-latitude chain of the SuperDARN HF radar system. Figure 2 shows an example of the map of the ionospheric total electron content (TEC) with three superimposed latitudinal slices of convection velocity vectors during the main phase of one such event. Flow pattern is computed globally but is shown only at three lines of constant longitude for clarity. A new element of this simulation was self-consistent calculation of TEC due to auroral precipitation in the RCM, allowing for determination of auroral boundaries with respect to the electric field structures. The double-peaked convection pattern in the dusk sector reflects magnetospheric processes responsible for the electrodynamics of the ring current particle injection, with the low-latitude peak collocated with the main ionospheric trough outside the main auroral flow.

Figure 3 further compares the westward component of convection velocity measured by one of the SuperDARN radars [7] with that computed by the RCM during another simulated event. These comparisons allow us, for the first time, to confirm that magnetospheric mechanisms responsible for sub-auroral polarization streams (SAPS) structures are directly controlled by the direction of the interplanetary magnetic field (IMF) z-component.

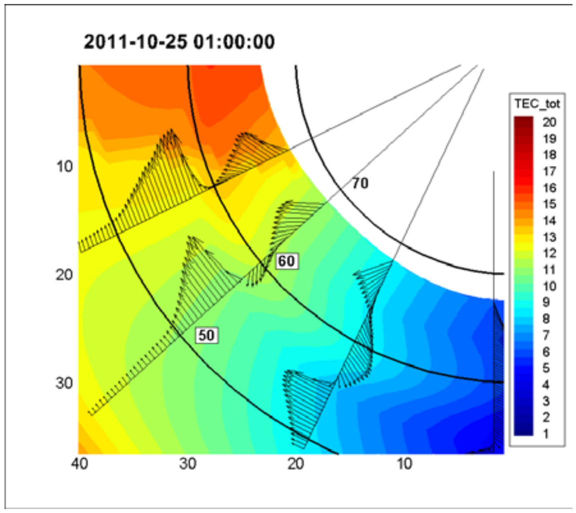

Figure 2. Ionospheric Projection of the Total Electron Content (TEC) (in color) and ExB Drift Flow Pattern (Vectors) During the Geomagnetic Storm of October 25, 2011.

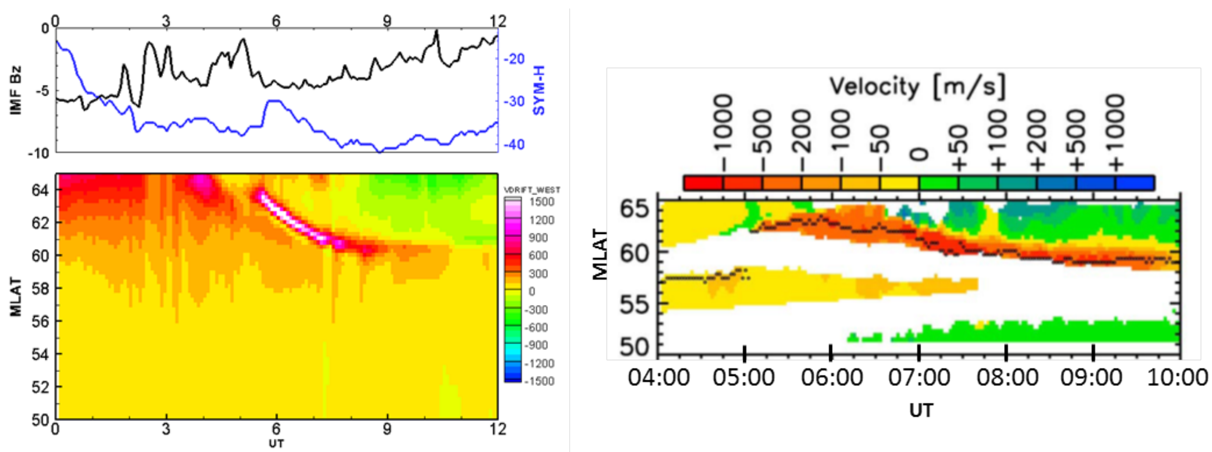

Figure 3. Comparison of Ionospheric Convection Flow Velocity (Westward Component) Measured by the SuperDARN Radar [7] (Right) and Computed by the RCM (Left) During the 2011-04-09 Geomagnetic storm.

4.3 Storm-time Ionosphere and Plasmasphere Structuring

We examined the relationship between structuring in the ionosphere and plasmasphere during quiet and storm times for the case of a major geomagnetic storm of March 31, 2001. Figure 4 [8] (top) shows color-coded contours of the electron density and contour lines of the total electrostatic potential in the magnetospheric equatorial plane (Sun is to the right). Mapping is done assuming dipolar magnetic field. The lowest level contour of the electron density is set at 30 cm^{-3}. The bottom of Figure 4 shows the global TEC (computed by integrating electron densities up to 2000 km) as well as the electrostatic potential from RCM. The contribution to the

TEC from plasma above 2000 km is ≲2%. The black contour line is 50 TECU; this contour level is mapped to the equatorial plane and is denoted by the red triangles in the top panel.

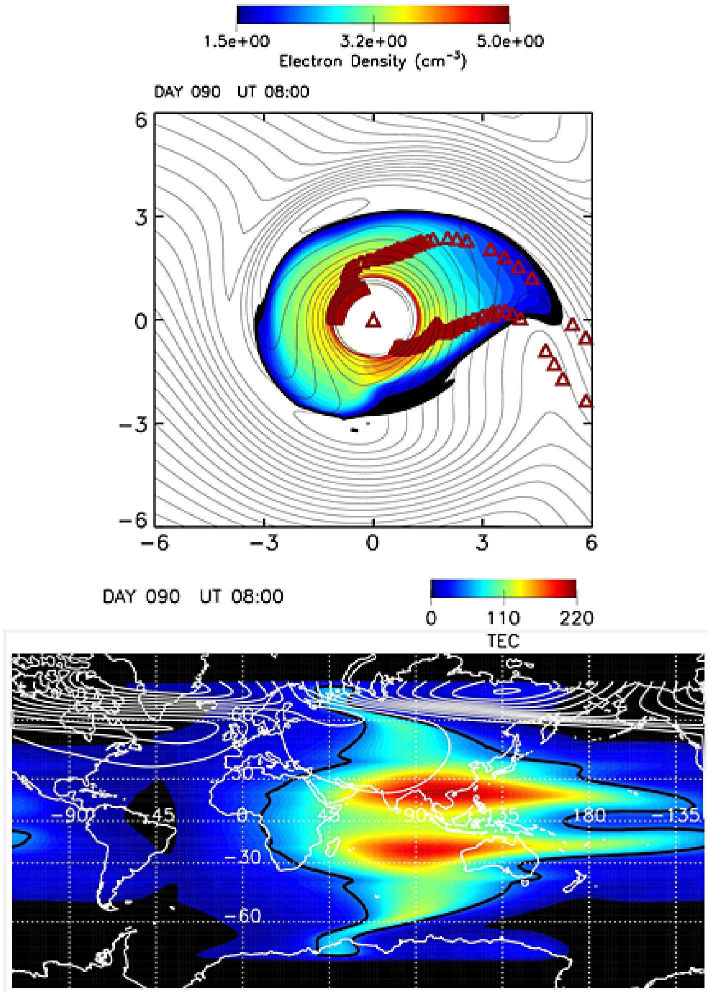

Figure 4. The Plasmasphere (Top) and Ionosphere (Bottom) at 08:00 UT during the Storm of 2001-03-31.

These results indicate the conjugate nature of structuring of electron densities (formation of ionization plumes) at various altitudes.

5. CONCLUSIONS

We have successfully demonstrated that the RCM can provide a superior space-weather product. The work under this preliminary project consisted of a modest amount of code development and more extensive validation and testing. In order to get initial understanding of the space weather potential capabilities of the RCM, we conducted a series of RCM event simulations and detailed comparisons of model output with available data. By varying relevant RCM input parameters for different model runs of the same event, and assessing their effects on the computed output comparisons, we established cause and effect relationships and guidance on how best to represent new physics in the RCM for predictive capabilities purposes. Establishing these relationships is an important step toward eventual inclusion of these effects into a realistic space weather model of substorm effects in the inner magnetosphere.

At the conclusion of this project, we have at our disposal a modern and flexible inner magnetospheric model coupled to the ionosphere that is suitable for both scientific studies as well as a prediction tool. We are able to run the model faster than “real time” on sufficiently modern computational platforms for many days of magnetospheric time. In collaboration with the multi-agency Community Coordinated Modeling center (CCMC), we made available a version of the RCM that runs in “real time” [9]. We plan on exploring additional ways to expand this line of work by finding ways to fund a more systematic effort in making the RCM a space weather prediction tool for magnetospheric and ionospheric studies relevant to space weather requirements.

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